NATIONAL BUREAU OF STANDARDS REPORT

10 008

FIELD EVALUATION OF A CABLE FAULT LOCATOR DEVELOPED BY NBS

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D. C. 20234.

[2] Located at Boulder, Colorado 80302.

[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

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NBS PROJECT **NBS REPORT**

2120414 March 1969 10 008

FIELD EVALUATION OF A CABLE FAULT LOCATOR DEVELOPED AT NBS

Prepared for
Naval Air Systems Command
Department of the Navy
Washington, D. C. 20360

By
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Photometry Section
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ABSTRACT

A prototype of a Cable Fault Locator (CFL) was designed and constructed by the National Bureau of Standards. This report covers the field testing and evaluation of this equipment. Much of the evaluation was a comparison of performance of the CFL with the performance of the AN/TSM-11, the equipment currently used for cable tracing and fault location. For the conditions tested, the capabilities of the CFL were equivalent or definitely superior to those of the AN/TSM-11. The depth of buried cables, which could not be measured reliably before, can usually be determined satisfactorily with the CFL. Although there were many definite improvements of the CFL over the earlier equipment, several areas of possible improvements are pointed out which should be considered if this equipment is to be produced in quantity.

1. INTRODUCTION

Modern airfields use a large number of electrical circuits for the airfield lighting, visual landing aids, and power circuits. These circuits are virtually all installed underground either by direct burial or in ducts of some type. The cables for these circuits are not readily accessible for inspection and often the route of the cable is unknown. A means of accurately locating the position of a fault for repair or the route of a cable to avoid damage from construction is frequently needed. Several types of equipment have been developed to answer this need but none of these devices have been fully satisfactory.

The cable test-detecting set AN/TSM-11[1/], developed in 1955, is the equipment currently used by the military services for tracing cable and for locating faults in these circuits. The AN/TSM-11 was designed for use in tracing direct-burial cable and in locating low-resistance-to-ground faults. It has been found suitable for these purposes except for some conditions when interference from power circuits or other signals are encountered. The AN/TSM-11 is easily portable and convenient to use but experience with this equipment revealed the need for a number of improvements. Some of these deficiencies are: The batteries for the receiver are not readily available; the response of

the indicating meter is not linear with signal field strength; the receiver amplifier is easily saturated; discrimination is inadequate in the receiver between the generated signal and harmonics of power frequencies and other signals used on airfields; and the vibrator does not adequately restrict the signal frequency. To improve capability in the location of high-resistance-to-ground faults and in the location of ungrounded opens and to eliminate the deficiencies listed above, a new design by the National Bureau of Standards (NBS) was undertaken rather than modification of the AN/TSM-11.

2. DESCRIPTION OF THE EQUIPMENT

The cable fault locator (CFL) developed by NBS consists of two major units; a test signal oscillator (TSO) and a detector unit (DU). Both units are easily portable and can be used at any desired location on the airfield. The equipment is described in NBS Report No. 9886 "Circuit Description of a Prototype Cable Fault Locator."2/

2.1. Test Signal Oscillator (TSO) Unit. The test signal oscillator is designed to be energized from either 110- to 130-volt, 55- to 60-hertz alternating current or 10- to 16-volt direct current. The oscillator can generate a square-wave signal of either 150, 270, or 570 hertz. The circuit for generating the signal is solid state and does not use a mechanical vibrator. Frequency shifts of the basic generated signal for 20 or 200 milliseconds at a repetition rate of 130 and 95 times per minute, respectively, can be selected to aid in identification of the test signal when interference is encountered. The output signal is isolated from the oscillator circuits by a transformer with output taps for approximately 6, 13, 28, 60, 130, 280, and 600 volts. An ammeter is provided to measure the power-amplifier collector current.

2.2. Detector Unit (DU). The detector unit is a tuned solid-state amplifier for detecting, amplifying, and indicating the radiation from the test signal in the cable being tested. It is a hand-held unit powered by four 1 1/2-volt pen-light cells. A ferrite-cored coil on a telescoping tube is used as the detecting element or probe. This probe is identical to that used with the AN/TSM-11. A switch for selecting the frequency used in the test and for testing the battery condition is provided. The gain can be adjusted by a logarithmic-response potentiometer.

3. FIELD TESTS AND RESULTS

3.1. General. The field tests were made at the Arcata Airport on previously installed cables. Some of the cables used in the tests were installed by direct burial in areas which were isolated from other circuits and others were near other circuits and conductors. Some of the cables were installed in metal pipe, frequently with other cables. Where suitable installations were available, the effects of interfering

power- and radio-frequency signals were evaluated. Each of the three TSO frequencies and the 20- and 200-millisecond Frequency Shift signals were evaluated for many of the test conditions.

3.2. Cable Tracing. Except for the differences of the CFL from the AN/TSM-11, the procedures used for tracing cable were similar to those given in section 2 of NBS Report No. 8596 "Guide to Use of AN/TSM-11 Cable Test-Detecting Set."[3/] The major differences in using the two devices were that for the CFL one of the three signal frequencies had to be selected on the TSO and DU, where the AN/TSM-11 had only a single frequency, and the matching of the signal generator output to the test circuit was determined in a different manner. For the AN/TSM-11 the generator output was matched to the circuit by selecting the position of the three Output Impedances which gave the highest voltage as determined by a supplemental voltmeter connected across the Output terminals. For the TSO, the Output Voltage tap-selector switch was placed on the lowest voltage position which would produce a reading on the panel meter above 0.7 amperes. Thus the over-current breaker would not trip. The impedance matching of the signal generators to the test circuit might differ appreciably. For the CFL, either of the test frequencies and either 0- or 20-millisecond Frequency Shift could be used on most circuits, but the 570-hertz signal and the 20-millisecond Frequency Shift were preferred unless difficulties indicated the need for another signal frequency. Both devices were usually satisfactory for tracing circuits, but for circuits with the end not connected to the signal generator open circuited, the CFL could trace closer to the end of the circuit.

3.2.1. Tracing Directly Buried Cables. Tracing directly buried cables which were isolated from other circuits was easy and accurate with both the CFL and the AN/TSM-11. For buried cables that were not isolated only two problems were encountered with the use of instruments of this type.

1. In some instances through leakage or inductive coupling, the signal was transferred to other cables or conductors such as pipes and the operator could follow the wrong path. Only by thoroughly investigating changes of signal strength could misleading indications be avoided.

2. In some areas there were strong interfering signals, especially at power frequencies. In such areas, using the Frequency Shift or interrupted signal was very valuable in identifying the test signal. The Frequency Shift of the CFL was preferred to the interrupted signal of the AN/TSM-11 because the meter indication was still useful and also the identification was better.

With both problems, the availability of more than one test frequency on the CFL was helpful. The 570-hertz signal was superior to the other frequencies when interference from power frequencies caused trouble; however, this signal was most likely to give a false lead onto other conductors. The 150-hertz signal was more likely to be bothered by power-frequency interference but in some cases the interference was worse with the 270-hertz than with the 150-hertz test signal. The 20-millisecond Frequency Shift of test signal was very helpful in many cases and its use did not present any special problems. The 200-millisecond Frequency Shift was not of particular improvement over the 20-millisecond Frequency Shift for any conditions tested.

3.2.2. Tracing Cable in Metal Duct. Much of the airfield lighting at the Arcata Airport is installed in steel pipe. (Not many airfields have cable installed in long lengths of steel pipe, but frequently magnetic shielding of cable in one form or another is encountered.) Usually either the CFL or the AN/TSM-11 could be used to trace cable in the presence of magnetic shielding, but much more often than for directly buried cable, the operator encountered problems and confusing indications. For either the CFL or the AN/TSM-11, the gain of the detecting unit had to be increased considerably to obtain meter indications comparable to that of a similar directly buried circuit. The use of increased gain made radiated signal interference problems more serious. Also the test signal heard in the headphones was not so easily identified, especially for the 150-, 250-, and 270-hertz signals. The interrupted or frequency shifted signals were frequently necessary for identification. The additional power from the TSO, the availability of the 570-hertz signal, and the improved discrimination of the DU made the CFL better for tracing circuits installed in steel pipe; however, the extra power and sensitivity and perhaps greater coupling of the 570-hertz signal would lead the operator farther astray with the CFL than the AN/TSM-11 if he lost the circuit or continued beyond its termination and followed some other conductor.

3.2.3. Tracing Energized Power Cables. The radiation from power circuits, which in some cases can be a hindrance when tracing cables, may be used to trace power cables without de-energizing the circuit. Both the CFL and the AN/TSM-11 were used successfully for tracing these circuits. The signal generator was not used. A high Gain setting of the detecting unit was needed. Starting from a known position over the circuit, if radiation could be detected, the circuit was traced in a manner similar to normal cable tracing using the meter indications or the tone in the headphones. Power signals gave a stronger indication with the detector-amplifier of the AN/TSM-11 than with the DU. Usually the strongest indication from power currents with the DU were obtained when the 150-hertz position was selected but occasionally the 270-hertz position gave a higher reading.

3.3. Locating Ground Faults in Cable. Ground faults can be classified as low-resistance-to-ground, high-resistance-to-ground, and multiple grounds. The basic procedure for locating any type of ground fault was similar to that given in Section 3 of NBS Report No. 8596.[3/] By following these procedures carefully, both the CFL and the AN/TSM-11 were used successfully to locate all three types of ground faults, but neither unit was satisfactory for locating certain ground faults in the presence of interference and shielding problems or for locating very high resistance-to-ground faults.

3.3.1. Ground Faults in Buried Cable. The CFL was more effective in locating ground faults in unshielded, directly buried cable than was the AN/TSM-11. Both types of equipment could locate low-resistance faults in these circuits to within two feet and usually to within less than six inches. The greater power output of the TSO and the increased gain and more linear response of the DU permitted detection of somewhat higher-resistance faults with the CFL than with the AN/TSM-11. Generally, any of the three test frequencies could be used to locate ground faults satisfactorily, but for certain conditions, one frequency was better than the others. The 570-hertz frequency had more power and greater sensitivity, especially in the headphones, but it sometimes had a stronger tendency to radiate into other conductors. The response from the 150- and 270-hertz signals was sometimes affected by radiation from power circuits which made the 570-hertz signal preferable. In seeking ground faults the continuous signal was slightly preferred, except that in cases of interference from extraneous sources the 20-millisecond Frequency Shift was desirable. The use of the Frequency Shift did not appreciably reduce the accuracy of locating ground faults.

3.3.2. Locating Ground Faults in Cable in Metal Pipe. Sometimes the CFL and AN/TSM-11 could be useful for locating ground faults on circuits installed in metal pipe, but results were not dependable. Tests on some circuits in pipe gave indications of changes in signal which probably were faults, but the cables could not be examined for the faults since they were inside of the pipe. In other cases, neither instrument was of value in locating ground faults in metal pipe. In a cable with insulation resistance to ground of 70 megohms, a short to ground was installed. Although the operator was aware that the intentional ground was installed, this ground was overlooked, but a definite fault indication was noted 400 feet beyond the actual ground and end of the cable. In this case, not only was there a failure to find the fault but misleading indications of faults were obtained. None of the test signal frequencies were satisfactory. When the cable was in steel pipe, any changes in signal strength seemed to be more gradual than occurred in directly buried cable.

3.4. Locating Open-Circuit Faults. The general procedure for using the CFL to locate open-circuit faults is similar to that for the AN/TSM-11. These procedures are given in Section 4 of NBS Report No. 8596.[3] The location of grounds in connection with open-circuit faults is discussed in this reference and the comments in Paragraphs 3.3.1 and 3.3.2 above apply for locating the ground. This discussion will be limited to ungrounded open-circuit faults.

3.4.1. Locating Ungrounded Open-Circuit Faults in Directly Buried Cable. The CFL as compared to the AN/TSM-11 could be used to more accurately locate ungrounded open-circuit faults in directly buried cable. With the TSO connected between ground and one side of the circuit, the DU Gain setting had to be increased appreciably over that required for grounds on the circuit to obtain a full-scale meter reading. Within a few hundred feet of the open fault, the signal strength decreased rapidly and usually became unusable before reaching the open fault. The Gain setting of the DU had to be at or near maximum when within the final 200 or 300 feet of the open fault, and any interfering radiation caused serious trouble at this sensitivity.

The CFL at each of the test frequencies was equally or more effective than the AN/TSM-11. For an open fault in a cable in an area with very little interference the AN/TSM-11 could be used to follow the cable to within 60 and 100 feet of the fault using the meter and to within 40 and 75 feet using the audible signal. (The distances quoted are respectively those obtained when the open was approached from the shorter and the longer run of cable.) With this same fault and using the CFL, the 150- and 270-hertz signals could be used to approach 5 to 10 feet nearer the fault than with the AN/TSM-11. The 570-hertz signal could be followed easily and accurately to within 25 feet of the fault and could be detected directly over the fault. The 570-hertz test signal was the most effective in approaching an open fault, but in some cases, could actually lead the operator across the fault without his recognizing it. The detectable signal had a tendency to spread over the ground as the open fault was approached. The capability of locating open faults with the CFL was also tested by connecting the TSO between the terminals of a series circuit which had an ungrounded open. This method of connection permitted the fault to be approached somewhat closer from both directions and the operator was not required to return to the TSO to change connections. However, with this method of connection, the fault might be passed over without recognition, especially when the 570-hertz signal was used.

3.4.2. Locating Ungrounded Open Faults in Cable in Metal Duct. Neither the CFL nor the AN/TSM-11 could be used to satisfactorily locate open faults in cable installed in steel pipe, nor was this capability expected. The shielding effect and concentration of the return signal made it too easy to pass over the fault without recognition. In one case with this type of fault, the operator proceeded several hundred feet beyond the open before finding any indication of a fault. Even when the location of this fault was known, indications of the open fault could not be detected.

3.5. Determining the Depth of Buried Cable. The AN/TSM-11 was of very little value in determining the depth of buried cable. The depths of cables in many conditions were accurately determined with the CFL, but there were some conditions when the depths obtained with the CFL were in error. The method used for determining the cable depth was to place the probe on the ground directly above the cable, adjust the DU Gain for a full scale or marked increment on the meter, then carefully raise the probe vertically until the meter reading was one-half the former value. The depth of the cable approximately equaled the height to which the probe was raised. This method of depth determination was very accurate for isolated direct-burial cable at depths of three feet or less. Some of the tests appeared to have about 10 percent error for depths of four feet and greater. If there was any radiated interference, the depth indication was likely to be in error. Each of the three test frequencies worked well for determining depth under good conditions, but the 570-hertz signal was less likely to be affected by radiated interference from power circuits. In some cases, the depth of cable in steel pipe was determined satisfactorily but in other cases the depth indications were seriously in error. Depth measurements near where the cable terminated or made a sudden change in direction were not accurate, as would be expected.

3.6. Miscellaneous.

3.6.1. Radio Frequency Interference. When using the DU in the vicinity of the airfield-lighting vault, the meter on the DU responded to some radio transmissions. The meter reading would suddenly increase or go off-scale, depending on the Gain setting, and the increased meter reading would be maintained for the duration of the radio transmission, but the audible signal was not affected except perhaps as a transient when the radio was keyed. The radio transmissions to which the DU meter responded were in the very high frequency (VHF) range, but other ranges might have a similar effect under the right conditions. Apparently the radio interference was rectified in the metering circuit and was not a signal in the audio range. The DU meter was more sensitive to radio frequency interference when on the 570-hertz position than on the 150- or 270-hertz position. The response to radio transmissions was never noted when working in the field away from the vault area. There have been no known instances of response to radio transmissions when using the AN/TSM-11, but this condition was not thoroughly investigated.

3.6.2. Mechanical Noise in DU. The DU was not noticeably microphonic (microphonics have been a problem with the AN/TSM-11), but there was one type noise which was bothersome. When the DU Gain was high and the probe struck weeds and grass or other objects, a very sharp sound was noted in the headphones. This noise was particularly bothersome when the signal strength was low and the path was being followed carefully under confusing conditions. This mechanical noise was observed on all three test frequencies but was unnoticed until the DU Gain was high. A method of reducing the effect of this mechanical noise was not determined, but using a shock absorbing covering over the probe surface might be helpful.

4. PHYSICAL EVALUATION

4.1. Physical Design. The physical design of the CFL is generally satisfactory but some improvements which are considered desirable are listed below.

1. DU is too large and heavy and its shape makes it uncomfortable to carry. This unit was much more tiring to use than was the AN/TSM-11 detector-amplifier. (In checking some long circuits, this unit may be carried for miles and held for a couple hours, hence a comfortable unit is required.)

2. The balance of the DU with the ferrite detecting element attached makes it awkward and its use tiring. The balance of the AN/TSM-11 detector-amplifier is better.

3. The cord from the headphones to the phone jack is too long and a shorter cord is needed. However, an extension section for special use may be desirable at times. (The cord and headphones are the same as those used with the AN/TSM-11.)

4. The headphones are heavy and interfere with hearing external noises. A single, lightweight earphone would be adequate. This would improve safety by permitting the operator to better hear outside noises, such as aircraft, when he is working along runways. In some cases the elimination of outside noises is useful, but most of the time this noise can be tolerated.

5. The DU, including the probe connector and phone jack, should be waterproof or as watertight as possible. This protection will be especially important when the unit is used in tracing underwater circuits.

5. EVALUATION OF ELECTRICAL CIRCUITS AND COMPONENTS

5.1. General. Both the CFL and the AN/TSM-11 operate on the same basic principles. As a result of more than a year of testing in the field, the effectiveness of the design changes in the CFL and areas of possible improvements can be reported.

5.2. Circuit Components. The CFL has been used in the test and evaluation program for nearly 18 months without a malfunction. The operating time during this period probably exceeds that which would be expected on most airfields in normal use. The improvement in quality of components, as well as the particular design, aid in the reduction of malfunctions. Near the end of this period the original set of

batteries in the DU were replaced. The type AA "penlite" batteries used in the DU are more readily available than are the batteries required for the detector-amplifier of the AN/TSM-11, and the life of the batteries in the DU is much longer. Also the battery test circuit on the DU was very useful.

5.3. Frequency Shift of TSO. The 20-millisecond Frequency Shift of the TSO test signal was preferred over the interrupted signal of the AN/TSM-11. This Frequency Shift was more comfortable to follow using the headphones than was the interrupted signal of the AN/TSM-11, but the major improvement was that the meter indication was usable with the 20-millisecond Frequency Shift. The 20-millisecond Frequency Shift could be used for all test conditions without seriously hampering performance. The 200-millisecond Frequency Shift did not appear to be an improvement over the 20-millisecond Frequency Shift for the conditions tested.

5.4. Test Signal Frequencies. The provision of the TSO for selection of any one of three test signal frequencies was an improvement. The 570-hertz signal was usually the best to use for this equipment, but on occasions one of the other frequencies was preferred. The use of solid-state components for signal generation provided a more stable frequency than the mechanical vibrator of the AN/TSM-11; however, the 570-hertz signal was actually 563 hertz.

5.5. Output Voltage Adjustment. The additional voltage taps and the increased maximum output voltage of the TSO as compared to the AN/TSM-11 signal generator were useful improvements. More voltage taps, or a continuously variable output, are desired. Often the maximum voltage that could be obtained from the TSO was approximately one-half that which might be expected because the next step, which may more than double the voltage, could not be used as it just tripped the circuit breakers. For open-circuit or high-resistance-to-ground faults and for tracing open circuits to the termination, the 600-volts output signal was helpful and in some cases even higher voltages would be useful.

5.6. Radio Frequency Interference. Some radio transmissions affected the meter indication of the DU but did not seriously affect the audio signal. A radio frequency interference filter to eliminate the effects of radio transmissions on the meter reading would be a desirable improvement.

5.7. Power Frequency Detection. In some instances, the DU was used conveniently to trace energized power circuits by using the 150-hertz input position. In normal use of the CFL for tracing cables and locating faults, this detection of power frequencies and resulting interference was a serious problem for which improved filtering is needed. If the filtering is improved, a 60-hertz position on the DU for detection of energized power circuits would be desirable.

5.8. Test Signal Distortion. The test signal from the signal generator was affected by the circuit to which the signal was applied. The waveform of the output voltage from the TSO and the signal generator of the AN/TSM-11 and output current to the circuit were determined for several test circuits. The approximately square-wave voltage output from the signal generators was often seriously distorted at the output terminals. The output current waveforms often had little resemblance to the output voltage waveforms. (A sine-wave signal was also applied to these same circuits and usually there was less distortion of the sine wave than of the square wave.) The waveforms of the detected signal at the input to the DU and at the headphones jack were determined. These waveforms were also distorted and in some cases appeared as damped oscillations; however, frequently the signal at the headphone jack was approximately a sine wave. (In most cases the sine-wave voltage test signal was less distorted than was the signal from the TSO.)

5.9. Detecting Element. As noted earlier the same detecting element or probe was used with both the CFL and the AN/TSM-11 units. The sensitivity of the probe depended on the circuit to which it was connected. Some tests indicated that the probe was poorly matched to the DU. These tests are discussed further in Paragraph 6.5.

6. DISCUSSION AND ANALYSIS OF RESULTS

6.1. Location and Installations. The field tests were made at the Arcata Airport where the soil has poor conductivity, often thousands of ohms resistance between ground rods three feet apart. There is also a vast network of steel pipe and abandoned cables buried throughout the airport. These conditions may not be typical of most airfields, and results at other locations may vary from those attained in these tests. The signal leakage to ground often concentrates on the buried pipes and cables at Arcata rather than dispersing through the ground. The concentration of return signal into the pipes and old cables serves as a false signal path to confuse the operator. The poor soil conductivity can effectively increase the impedance of high-resistance ground faults, and the change in signal strength may be reduced.

Much of the cable installed at Arcata is in steel pipe used as ducts. Not many airfields have similar installations, but the results from tests on cables in steel pipe indicate the type of performance that can be expected from other cases of magnetic shielding. The magnetic shielding effect occurs with armored cables, cable in short lengths of pipe, cable in raceways, and perhaps cables below counterpoises. (No tests were made on armored cables or cables near counterpoises as such cables were not available.) Any magnetic shielding reduces the detected signal strength but usually the signal can be followed. Frequently ground-type faults can be located in the presence of magnetic shielding, but for some conditions even low-resistance grounds cannot be detected. The presence of other current-carrying cables in the same or adjacent

pipes, the concentration of return signal into the pipe, and the induction of test signal into other cables often add to the confusion in locating faults or lead the operator astray. The tests of cables in steel pipe indicate the extreme effects of magnetic shielding. Tests of circuits in armored cables and in conjunction with counterpoises are needed to determine better approaches to fault location in these conditions.

6.2. Use and Comparison of Test Frequencies. For most conditions when using the CFL, the 570-hertz signal with the 20-millisecond Frequency Shift was satisfactory or preferred. As a single frequency for this equipment, this frequency would be preferred, but the other frequencies were not evaluated on an equal basis with the 570-hertz frequency. With a given test circuit the output voltage of the TSO varied only slightly with test-signal frequency. However, the changes in the current in the test circuit will be a function of the type of impedance of the circuit. Because of the characteristics of the sensing element and the input of the DU, the DU favored the 570-hertz signal by a factor of approximately three. When using the headphones, the human ear also favors this signal appreciably. Some of these factors favoring the 570-hertz signal are inherent and cannot be made comparable by design changes. The higher frequency usually will be detectable to a position nearer an open fault or open termination of a circuit; however, this signal can lead the operator farther astray if he is misled onto a wrong circuit or conductor.

6.3. Signal Waveforms. The waveforms of test signals were studied with an oscilloscope. The basic output voltage signals from both the TSO and the AN/TSM-11 signal generator are square waves, but the TSO signal normally has a sharp peak at the leading edge of the voltage wave. These output voltage waveforms are often seriously distorted by the circuit to which the signal generators are connected. The voltage waveform of the TSO is also affected by the signal frequency and the Output-Voltage switch position with the distortion increased as the frequency or Output Voltage are increased. These test signals and a sine-wave voltage of comparable frequency were applied to several circuits of various types, both open circuits and grounded circuits, and the effects on the output voltages, on the current into test circuit, on the detected signals from the probe, and at other points were observed. The sine-wave signals were least distorted and the TSO signal was more likely to be seriously affected. The impedances of the generators were not equal nor were they matched to the loads. This difference in impedance was responsible for the greater distortion of the TSO signal. Increasing the output impedance of the TSO would reduce the distortion of the test signal current waveforms but would also reduce the current into the test circuit.

The detected signal is dependent on the test current in the circuit not the voltage applied to the circuit. The amplitude and wave shape of the current in the test circuit are functions of the circuit impedance and the applied voltage waveform, amplitude, and frequency. Since these functions are interrelated, tests were made to compare the effectiveness of the TSO signal and the sine-wave signal on some installed circuits. In these tests, the sine-wave voltage applied to the circuit was at the

same amplitude and frequency as the TSO signal, and the DU was used to detect and measure both signals. The sine-wave signal gave meter readings 10 to 20 percent greater than those from the TSO signal. The audible signal from the sine-wave signal was preferred at 570 hertz, but was less satisfactory at 150 hertz. Neither signal showed any marked advantage in locating either ground or open faults. For the present DU, any improvement by changing the test signal to a sine wave would be minor.

6.4. Matching Signal Generator to Test Circuit. The output power and voltage of the TSO are increased by a factor of two over the AN/TSM-11 signal generator and the TSO has many more voltage taps for selection but this additional voltage is not always usable. The operation of the circuit breakers to deenergize the equipment when the collector current exceeds a given value may reduce the voltage by a factor of two because the next tap will just trip the circuit breaker. A continuously variable output voltage or smaller voltage steps would be convenient. This over-current protection usually functions before the voltage applied to the test circuit reaches a peak. The voltage from the TSO probably can equal or exceed that from the AN/TSM-11 signal generator in nearly all conditions. However, for open circuit tracing or fault location or in cases of radiation interference, a still higher voltage would be useful.

6.5. Sensing Element. Better filtering in the DU is needed for some conditions. This filtering could be aided by proper matching of the sensing element or probe to the DU. A frequency-response test was made with the probe connected to the DU and to the AN/TSM-11 detector-amplifier. The test was made by applying a variable-frequency, constant-voltage, sine-wave signal to a circuit with the lead to the circuit wound around the ferrite core of the probe and measuring the signal amplitude at the connector of the probe. When the test signal was connected to the DU, maximum response occurs at approximately 1550 hertz. The response is more than four times that obtained at 570 hertz and over 10 times that at 150 hertz. With the probe connected to the AN/TSM-11 detector-amplifier, the peak response occurs at approximately 270 hertz and was down by a factor of two at 120 and 740 hertz. Better matching of the probe to the DU for the test frequencies, especially at 570 hertz, should be a worthwhile improvement.

Some earlier tests with the AN/TSM-11 using an 8-inch loop as the sensing element instead of the ferrite-core probe indicated that the loop was more critical in directional alinement than was the probe. This limiting of direction might be helpful where radiated interference or stray paths of signal cause problems. Such a loop could be provided for use as a substitute for the probe in problem areas.

6.6. Cable Tracing Problems. The CFL and AN/TSM-11 are both satisfactory for tracing most cables, and the CFL was often useful beyond the capabilities of the AN/TSM-11. Still, conditions occur when circuits cannot be followed satisfactorily with the CFL. The problems in tracing cable are either from radiation interference from other current-carrying circuits or from the operator following stray test signal onto other conductors. Improvements in the CFL might be helpful for these problem areas. Better filtering of the DU to further reduce the effects of power frequencies and harmonics may be possible. As compared to the response at any selected test signal frequency, the DU response at any harmonic of the power frequency should be down at least 10, and preferably 20, decibels. Matching the DU to the probe may aid in this filtering. Increased power of the test signal would help in cases of power signal interference and in approaching the termination of open circuits. An auxiliary unit to increase the power might be a possibility.

6.7. Ground Fault Location. Locating low-resistance ground faults present few problems with this type equipment except in the presence of signal interference or magnetic shielding. Results on high-resistance faults, single or multiple, depend on conditions accompanying the faults. A very high-resistance single fault can be detected under favorable conditions but a fairly low-resistance fault will be hard to locate under difficult conditions. Many ground faults, especially multiple grounds, require "the try-and-see if you find it" approach. The probability of finding such faults is improved by clearing all faults which can be located; testing from both ends of the circuit, if practical; and evaluating all possible fault indications carefully.

6.8. Open-Circuit Faults. Precise location of ungrounded open-circuit faults can seldom be accomplished with equipment of this type, but the CFL produces better accuracy than does the AN/TSM-11. The higher frequency and increased power in the test signal are the major reasons for this improvement. An increase of power in the signal would be one method of improving capability of locating open faults. An ungrounded open cable appears basically as a capacitor to the TSO. The square-wave test signal is differentiated by the cable capacitance and the current into the cable is a sharp pulse. Tests comparing a sine-wave signal of equal amplitude and frequency to the square wave from the TSO into open circuits did show some increase in response of the DU to the sine wave, but the accuracy in locating ungrounded open faults was not markedly improved. A sine-wave signal might be beneficial if it can be attained without too much extra cost.

6.9. Depth Determination. A method of determining the depth of buried cable is needed for maintenance of underground circuits. In using this type equipment for locating ground faults, a depth measurement is often needed because an increase in cable depth gives a decrease in response

similar to the change at a fault. The AN/TSM-11 is not satisfactory for measuring cable depth. The CFL can usually be used to satisfactorily determine the depth of a cable. The principle of the method used is based on the fact that the magnetic field strength around a long, straight conductor carrying a current is inversely proportional to the distance from the conductor. Thus, if the response of the detector is linear with the magnetic field strength, a decrease in response of one-half would accompany a doubling of distance from the conductor. Since the response of the DU is linear with the strength of the detected signal, by making a reading at the ground surface directly over a cable with the test signal and then raising the probe until the meter reading is reduced to one-half the former reading, the depth of the buried cable should equal the distance the probe is raised. The response of the AN/TSM-11 detector-amplifier is not linear, thus it is not satisfactory for depth measurements.

Depth measurements in the vicinity of turns in the cable path are often in error. To measure depth accurately, it is necessary to stay 10 to 20 feet from turns in the cable. Some depth measurements of cable in steel pipe give satisfactory results but others do not. Depth measurements in the presence of detectable signals from another source or of the test signal in another conductor are likely to be in error. The presence of other signals causes most of the error in the unsatisfactory measurements of cable in pipe. To avoid the effects of magnetic shielding and of changes in direction of the cable, depth measurements should be at least 10 feet from light fixtures and handholes.

7. CONCLUSIONS AND RECOMMENDATIONS

A person with little experience and training can use the CFL successfully in many situations, but in cases of radiation interference, magnetic shielding, leakage and stray signals, and certain types of faults, experience and careful use are required. The CFL is a definite improvement over the AN/TSM-11 in many respects; however, there are still conditions where satisfactory results cannot be obtained. From the results of these field tests, some improvements are recommended.

7.1. <u>Recommendations for Improvements</u>. Certain features of the CFL should be changed before production in quantity. These needed improvements are as follows:

1. Redesign the DU for better balance, shape, and size. The balance should consider the operating position with the probe attached. Eliminate square corners and edges, especially where the unit rests in the hand.

2. Provide a type of headphones that will be convenient to wear and not interfere with hearing traffic or aircraft. A single earphone should be satisfactory. Also shorten the

length of the cord from the headphones to the DU. An extension cord arrangement of short sections is desirable.

3. Make the DU, including the connector for the probe and the headphone jack, waterproof or as watertight as possible.

4. Investigate the savings that may result from eliminating the 270-hertz test signal and the 200-millisecond Frequency Shift. If the savings are appreciable, remove these features.

5. Improve the filtering of the DU, especially for the 570-hertz frequency. The response at all harmonics of the power frequency should be down at least 10 decibels and preferably down 20 decibels.

6. If the filtering of the DU is improved significantly, provide a circuit for detecting 60-hertz signal for use in tracing energized power circuits.

7. Provide better matching of the sensing element to the DU circuits to improve filtering.

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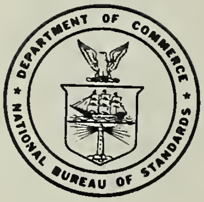

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